

**FINAL PROGRESS REPORT FOR  
O.N.R. GRANT N00014-97-1-0822: June 1, 97 – Sep 1, 00**

**Multichannel/Multisensor Signal Processing In Uncertain  
Environments With Application To Multitarget Tracking**

This research project was concerned with two distinct aspects of analysis and processing of signals received at multiple sensors from multiple sources when the operating environment is highly uncertain and unstructured. In part I, a general approach based upon an independent component decomposition (ICD) was investigated involving as few assumptions as possible compared to existing literature. The approach was developed in conjunction with specific, useful applications such as space and time diversity multiaccess/multiuser digital communications. In part II focus was on maneuvering target tracking using kinematic models.

**WORK COMPLETED:** Progress was made on the following major aspects of the project:

- 1 TRACKING MANEUVERING TARGETS USING MULTIPLE KINEMATIC MODELS:** We developed a new method (interacting multiple model (IMM) fixed-lag smoothing) for tracking a single maneuvering target in a "clean" environment (no clutter). This work has been reported in [1] and [4]. We extended this approach to tracking a single maneuvering target in clutter in [2] and [5]. Application of this technique to tracking multiple maneuvering targets in clutter is reported in [3] and [6].

We developed a suboptimal filtering algorithm by applying the basic IMM approach and the Joint Probabilistic Data Association (JPDA) technique to a Markovian switching system. A suboptimal fixed-lag smoothing algorithm was also developed by applying the IMM and the JPDA approaches to a state-augmented system. The developed algorithms are applicable to track maintenance (assuming that for each target a track has been formed). A simulation example involving tracking of two highly maneuvering targets (where two sensors, a radar and an infrared sensor, are used) shows that the proposed smoothing algorithm achieves a significant improvement in the accuracy of track estimation by introducing a small time lag between the instants of estimation and latest measurements whereas the computational load for target state estimation increases linearly with lag and that for data association remains the same. Interestingly, other researchers (e.g. Koch, IEEE Trans. AES, pp. 2-14, Jan. 2000) have also recently considered state/probability smoothing (named retrodiction – as an antonym of prediction – by Drummond) in order to better discriminate among tracks of closely spaced targets. Koch considers a version of smoothing that requires exponentially increasing computational burden with time lag  $d$  whereas our method of state augmentation increases the computational cost only linearly with lag  $d$ .

The work discussed above resulted in the PhD thesis of Bing Chen.

- 2 INDEPENDENT COMPONENT DECOMPOSITION AND ITS APPLICATIONS:**  
Here we have investigated several approaches for independent source separation, equalization,

channel estimation, independent component decomposition and multiuser detection for DS-CDMA systems. The results have been reported in refs. [7]-[23] where further details may be found.

Portions of the work referred to above resulted in the PhD theses of Bin Huang and Tongtong Li.

## PAPERS PUBLISHED

### Target Tracking Papers

- [1] B. Chen and J.K. Tugnait, "An interacting multiple model fixed-lag smoothing algorithm for Markovian switching systems," in *Proc. of IEEE 37th Conf. Decision & Control*, pp. 269-274, Tampa, FL, Dec. 16-18, 1998.
- [2] B. Chen and J.K. Tugnait, "Multisensor tracking of a maneuvering target in clutter using IMM/PDA fixed-lag smoothing," in *Proc. of 1999 American Control Conference*, San Diego, CA, June 1999.
- [3] B. Chen and J.K. Tugnait, "Multisensor tracking of multiple maneuvering targets in clutter using IMM/JPDA fixed-lag smoothing," in *Proc. of IEEE Conf. on Decision & Control*, pp. 5058-5063, Phoenix, AZ, Dec. 7-10, 1999.
- [4] B. Chen and J.K. Tugnait, "Interacting multiple model fixed-lag smoothing algorithm for Markovian switching systems," *IEEE Trans. on Aerospace & Electronic Systems*, vol. AES-36, pp. 243-250, Jan. 2000.
- [5] B. Chen and J.K. Tugnait, "Multisensor tracking of a maneuvering target in clutter using IMM/PDA fixed-lag smoothing," *IEEE Trans. Aerospace & Electronic Systems*, vol. AES-36, pp. 983-992, July 2000.
- [6] B. Chen and J.K. Tugnait, "Tracking of multiple maneuvering targets in clutter using IMM/JPDA filtering and fixed-lag smoothing," *AUTOMATICA* (the IFAC journal), to appear Feb. 2001.

### Comm./Signal Processing Papers

- [7] J.K. Tugnait, "On multi-step linear predictors for MIMO FIR/IIR channels and related blind equalization," in *Proc. of 1998 IEEE Digital Signal Processing Workshop*, Paper #110, Bryce Canyon, Utah, Aug. 1998.
- [8] J.K. Tugnait, "On linear predictors for MIMO channels and related blind identification and equalization," *IEEE Signal Processing Letters*, vol. SPL-5, pp. 289-291, Nov. 1998.
- [9] J.K. Tugnait, "On blind separation of convolutive mixtures of independent linear signals in unknown additive noise," *IEEE Trans. Signal Processing*, vol. SP-46, pp. 3117-3123, Nov. 1998.
- [10] J.K. Tugnait and Bin Huang, "Second-order statistics-based blind equalization of IIR single-input multiple-output channels with common zeros," *IEEE Trans. Signal Processing*, vol. SP-47, pp. 147-157, Jan. 1999.
- [11] J.K. Tugnait, "Adaptive blind separation of convolutive mixtures of independent linear signals," (invited paper), *Signal Processing* (the EURASIP Journal), vol. 73, Issue 1-2, pp. 139-152, Feb. 1999.
- [12] J.K. Tugnait and B. Huang, "Multi-step linear predictors-based blind equalization of multiple-input multiple-output channels," in *Proc. IEEE 1999 Intern. Conf. Acoustics, Speech, Signal Processing*, Phoenix, AZ, vol. 5, pp. 2949-2952, March 15-19, 1999.

- [13] J.K. Tugnait and B. Huang, "Blind channel estimation and equalization of multiple-input multiple-output channels," in *Proc. IEEE 1999 Intern. Conf. Acoustics, Speech, Signal Processing*, Phoenix, AZ, vol. 5, pp. 2707-2710, March 15-19, 1999.
- [14] J.K. Tugnait, "A multi-delay whitening approach to blind identification and equalization of SIMO channels," in *Proc. 2nd IEEE Signal Processing Workshop on Signal Processing Advances in Communications*, Annapolis, MD, pp. 223-226, May 9-12, 1999.
- [15] J.K. Tugnait, "Multistep linear predictors-based blind equalization of FIR/IIR single-input multiple-output channels with common zeros," *IEEE Trans. Signal Processing*, vol. SP-47, pp. 1689-1700, June 1999.
- [16] J.K. Tugnait and B. Huang, "New results on blind identification and equalization of MIMO channels/systems," (invited paper), in *Proc. IEEE Conf. on Decision & Control*, pp. 168-173, Phoenix, AZ, Dec. 7-10, 1999.
- [17] J.K. Tugnait, "New results on second-order statistics-based blind identification and equalization of SIMO channels," in *Proc. IEEE Globecom'99: Symp. on Advanced Signal Proc. for Commun.*, Rio de Janeiro, Brazil, Dec. 5-9, 1999, pp. 2147-2151.
- [18] J.K. Tugnait and B. Huang, "Multistep linear predictors-based blind identification and equalization of multiple-input multiple-output channels," *IEEE Trans. Signal Processing*, vol. SP-48, pp. 26-38, Jan. 2000.
- [19] J.K. Tugnait and B. Huang, "On a whitening approach to partial channel estimation and blind equalization of FIR/IIR multiple-input multiple-output channels," *IEEE Trans. Signal Processing*, vol. SP-48, pp. 832-845, March 2000.
- [20] Tong-tong Li and J.K. Tugnait, "A code-constrained constant-modulus approach to blind detection of asynchronous CDMA signals in multipath channels," in *Proc. 2000 Conf. on Information Sciences & Systems*, pp. TAB7-13:17, Princeton University, NJ, March 15-17, 2000.
- [21] J.K. Tugnait and Tong-tong Li, "Blind detection of asynchronous CDMA signals in multipath channels using code-constrained inverse filter criteria," in *Proc. IEEE 2000 Intern. Conf. Acoustics, Speech, Signal Processing*, pp. V-2461:2464, Istanbul, Turkey, June 2000.
- [22] Tong-tong Li and J.K. Tugnait, "A multistep linear prediction approach to blind asynchronous CDMA channel estimation and equalization," in *Proc. IEEE 2000 Intern. Conf. Acoustics, Speech, Signal Processing*, pp. V-2925-2928, Istanbul, Turkey, June 2000.
- [23] Bin Huang and J.K. Tugnait, "A multi-delay whitening approach to blind identification and equalization of MIMO channels," in *Proc. IEEE 2000 Intern. Conf. Acoustics, Speech, Signal Processing*, Istanbul, Turkey, June 2000.

### STUDENTS SUPPORTED

1. Bing Chen, Ph.D. Dissertation, "Algorithms for Multisensor Maneuvering Target Tracking," Auburn University, December 1999. (Is now with IBM Corp., Hopewell Junction, NY.)
2. Bin Huang, Ph.D. Dissertation, "Blind Equalization and Identification of Communication Channels," Auburn University, December 1999. (Is now with BOPS (billions of operations per second), Inc, Chapel Hill, North Carolina.)
3. Tong-tong Li, Ph.D. Dissertation, "Blind Channel Estimation and Multiuser Detection for CDMA Systems over Multipath Channels," Auburn University, August 2000. (Will join Lucent in Sept. 2000).

**REPORT DOCUMENTATION PAGE**Form Approved  
OMB NO. 0704-0188

Public Reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comment regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE 28 August 2000		3. REPORT TYPE AND DATES COVERED Final Progress, 1 June 1997 - 1 Sep 2000	
4. TITLE AND SUBTITLE Multichannel/Multisensor Signal Processing In Uncertain Environments With Application To Multitarget Tracking				5. FUNDING NUMBERS ONR G N00014-97-1-0822	
6. AUTHOR(S) Jitendra K. Tugnait					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Auburn University Dept. of Electrical & Computer Eng. Auburn, AL 36849				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)  Office of Naval Research Ballston Center Tower One One North Quincy Street Arlington, VA 22217-5660				10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
12 a. DISTRIBUTION / AVAILABILITY STATEMENT  Approved for public release; distribution unlimited.				12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  This research project was concerned with two distinct aspects of analysis and processing of signals received at multiple sensors from multiple sources when the operating environment is highly uncertain and unstructured. In part I, a general approach based on an independent component decomposition (ICD) was investigated involving as few assumptions as possible compared to the existing literature. The approach was developed in conjunction with specific, useful applications such as space and time diversity multiaccess/multiuser digital communications. In part II focus was on maneuvering target tracking using kinematic models. This report briefly describes the results obtained on the above two aspects of the project. The details may be found in 10 published journal articles, 13 conferences papers and 3 PhD theses. A list of these publications is provided.					
14. SUBJECT TERMS Maneuvering target tracking, IMM method, source separation, blind equalization, multiuser detection, DS-CDMA systems.				15. NUMBER OF PAGES	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION ON THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED		20. LIMITATION OF ABSTRACT  UL	

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)  
Prescribed by ANSI Std. Z39-18  
298-102**DTIC QUALITY INSPECTED 4**